NON-PUBLIC?: N
ACCESSION #: 9105070250
LICENSEE EVENT REPORT (LER)

FACILITY NAME: South Texas, Unit 1 PAGE: 1 OF 11

DOCKET NUMBER: 05000498

TITLE: Reactor Trip Due to a Generator Ground Fault Relay Actuation Caused by a Stator Coil End Turn Failure
EVENT DATE: 11/24/90 LER #: 90-025-01 REPORT DATE: 05/01/91

OTHER FACILITIES INVOLVED: DOCKET NO: 05000

OPERATING MODE: 1 POWER LEVEL: 100

THIS REPORT IS SUBMITTED PURSUANT TO THE REQUIREMENTS OF 10 CFR SECTION:
50.73(a)(2)(iv)

LICENSEE CONTACT FOR THIS LER:
NAME: Charles Ayala - Supervising Licensing Engineer TELEPHONE: (512) 972-8628

COMPONENT FAILURE DESCRIPTION:
CAUSE: B SYSTEM: TJ COMPONENT: GEN MANUFACTURER: W120
REPORTABLE NPRDS: Y

SUPPLEMENTAL REPORT EXPECTED: NO

ABSTRACT:

On November 24, 1990, Unit 1 was in Mode 1 at 100% power. At 1448 hours, the generator running ground fault relay actuated due to a stator coil end turn failure which initiated an automatic reactor trip. All systems responded as expected. Feedwater isolation occurred on low Reactor Coolant System average temperature, and Auxiliary Feedwater (AFW) actuated on low - low steam generator level as expected. Initial internal inspection of the generator revealed damage to the end turn of bottom stator coil #23 at the turbine end. The stator coil end turn failure was due to vibration-induced fatigue cracking brought on by excessive end turn vibration which resulted from structural degradation of generator blocking and lacing. The most probable cause of the structural degradation was latent damage that resulted from the January 20, 1989 generator hydrogen cooling transient (refer to LER 89-005). Extensive remedial actions to repair the damage have been implemented for

the Unit 1 generator. Corrective actions include installation of "Winding Improvement Modules;" installation of an End Turn Vibration Monitoring System; and, installation of a dual tower hydrogen gas dryer. The latter two actions are also scheduled to be implemented in Unit 2. A Turbine-Generator Task Force, consisting of HL&P and Westinghouse personnel, has been initiated to address issues of concern regarding the Units 1 & 2 turbine-generator and to exchange relevant operational information.

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END OF ABSTRACT



DESCRIPTION OF EVENT:

On November 24, 1990 Unit 1 was in Mode 1 at 100% reactor power. At 14:49:22 the main generator "Stator Cooling Water System Trouble" annunciation was received in the Main Control Room. At 14:49:23, the 64R/G1 generator running ground fault relay actuated, thus initiating an automatic Unit 1 reactor trip. All plant systems responded as expected. Feedwater isolation occurred on low Reactor Coolant System average temperature, and Auxiliary Feedwater (AFW) actuated on low - low steam generator level as expected. The NRC was notified at 1735 hours.

Initial internal inspection of the generator revealed a damaged area at the end turn of bottom stator coil #23, which is located between the nine and ten o'clock positions when viewed from the turbine end.

Figures 1 and 2 provide general illustrations of the areas of concern within the generator.

Investigation and recovery teams were formed to evaluate the failure and implement corrective actions. An inspection of the generator was performed. The following was observed:

- A significant amount of the copper header box material was missing, presumably vaporized or melted by electrical arcing.

- The teflon hose which connects the stator cooling water distribution header to the damaged coil was damaged.

- The cooling water manifold nipple associated with the failed stator coil was eroded away from the inside, presumably by an electrical arc.

- There was no damage on the adjacent manifold nipples on either side of the eroded nipple.

- The structural damage to the end turn winding blocking and lacing was severe on the turbine end of the generator. The exciter end blocking and lacing was essentially intact.

- There was lead carbonate contamination on the end turn windings on the turbine end of the generator. Lead carbonate is produced when moisture present in the hydrogen cooling gas reacts with brazing flux residue utilized for installation of the hydrogen cooler fins.



DESCRIPTION OF EVENT (Continued):

The Westinghouse generator end turn construction is designed to rigidly connect all the end turns together to preclude excessive vibration of individual turns. The structural connections utilize non-conductive materials such as glass and textiles which are impregnated with epoxy-type resins.

During the week of November 26, 1990, Westinghouse personnel performed end turn impact tests on both Unit 1 and Unit 2 generators. The purpose of these impact tests was to determine the natural frequency of the generator end turn assembly with respect to the 120 Hz resonant frequency of that assembly. The general acceptance criteria for the impact test is an end turn natural resonance frequency above 130 Hz. The Unit 2 test was performed to determine the condition of that unit and also to provide a baseline for the Unit 1 test. The impact test results showed that the Unit 2 turbine end natural frequency was 134 Hz and the Unit 1 turbine end natural frequency was 109 Hz. Exciter end impact testing on Unit 2 was not performed, since prior Westinghouse experience indicated that exciter end natural frequencies are substantially higher than turbine end natural frequencies.

Westinghouse personnel interpreted the impact test results as being "excellent" for Unit 2 and "unacceptable" for Unit 1. The Unit 1 end turn resonance below 120 Hz suggests that the end turn assembly had already passed through the natural resonant frequency and been subjected to excessive vibration. This assumption is validated by the Unit 1 visual observations, which revealed significant end turn "dusting",

"greasing", and broken blocking and lacing. These conditions are all confirmations of excessive end turn vibration. By contrast, the Unit 2 visual observations revealed no such telltale signs of excessive end turn vibration, as was confirmed by the impact testing.

Subsequent investigations revealed that similar stator coil end turn failures had occurred on two other Westinghouse large domestic four-pole generators. These failures occurred at the Public Service Electric & Gas Salem Unit 1 in February, 1984, and Salem Unit 2 in October, 1984. The basic failure mechanism determined at Salem, other than the specific initiating event, was also determined to be applicable to the STPEGS failure. The following is a description of the failure mechanism.

a) The structural bonding capability of the stator end turn assembly is degraded by some transient event, such as a thermal transient due to overheating in the generator or by an electromechanical transient such as a close-in fault.



DESCRIPTION OF EVENT (Continued):

b) The 120 Hz alternating magnetic forces which normally act upon the end turn assembly caused vibratory stresses, which further loosened the structural supports of the end turns. Continued degradation of the end turn bracing led to even greater overall coil looseness, increasing vibration levels, and increased relative motion between stator coils.

c) A fatigue crack developed in one of the current-carrying stator coil header caps; first in the solder bond between the series connection strands and header cap ferrule; then progressing into the copper header cap ferrule itself. The increasing vibratory stresses were the primary cause of the crack initiation and propagation.

d) The fatigue crack propagated along the ferrule-to-header cap interface, parallel to the series connection strands, effectively reducing the stator coil current-carrying cross section, until the ferrule either fractured or melted off. This opened the electrical circuit and resulted in an electrical arc.

e) A significant portion of the ferrule, series connection strands

and header cap were melted/vaporized by the electrical arc. When the arc broke through into the water chamber, the resultant pressure of the steam, arc products and hydrogen rotor cooling gas forced the molten/vaporized metal back through the teflon cooling hose into the stator cooling water manifold. The arcing was of extremely short duration and would essentially resemble an explosion.

f) A ground current developed in the partially ionized copper vapor flowing through the teflon hose, which resulted in the ground fault relay actuation. The pressures generated during the arc, in combination with the hydrogen pressure in the generator, would have forced the cooling water out of the local fault area during the fault condition.

Definition of this failure mechanism raised the concern that additional fatigue cracking could exist in other stator coils in the Unit 1 generator. Nondestructive examinations of all stator coil end turns were performed utilizing visual, eddy current, replication and ultrasonic testing methods. These examinations revealed cracks in solder bonds between the series connection strands and header cap ferrules of eighteen stator coils, cracks in the copper header cap ferrules on six of those stator coils, and an internal defect, determined by ultrasonic testing, in one additional stator coil. Metallurgical analyses of the cracked header cap ferrules confirmed that the cracking was the result of a vibration-induced fatigue mechanism.



DESCRIPTION OF EVENT (Continued):

Extensive disassembly of the generator was required to effect the necessary repairs. The following is a summary of the repair activities which were performed on the generator, as recommended by Westinghouse:

a) All top stator coils were removed from the generator. All stator coils with copper ferrule crack indications were replaced utilizing existing spare coils.

b) All the stator coil slots were re-wedged following re-installation of the top coils.

c) All the end turn blocking and lacing on both the turbine end and exciter end of the generator was removed and replaced.

d) The stator core through-bolts, building bolts and bore rings were re-tightened to 110% of design torque values.

e) Existing series connection solder joint cracks were removed as a consequence of the repair activities, as all series connections were required to be de-soldered to facilitate top coil removal.

f) Areas of high mechanical stress concentration on the stator coil header caps were machined to reduce the stresses.

g) The copper, carbon and lead carbonate contamination inside the generator was removed,

The actions noted above returned the generator to its original design condition. Improvement of the structural integrity of the end turn winding assemblies beyond the original design was implemented by installation of "Winding Improvement Modules" on both the turbine end and exciter end of the generator. These modules consist of the following:

a) Radial Winding Clamps, which are installed in radial tension to reduce relative radial motion and resultant wear between a top coil, bottom coil and associated strain block.

b) Banded Three-Piece Diamond Spacers, which are installed in compression between adjacent coil pairs to provide additional circumferential consolidation of the end turn winding structure.



DESCRIPTION OF EVENT (Continued):

c) Decoupled Bottom Coil Support Bracket, which provides rigid radial end turn support for fault conditions; allows axial end turn movement for thermal expansion; and decouples the end turns from the stator core to provide improved end winding dynamics.

d) Modified Deep-Beam Series and Phase End Blocking, which provides improved top-to-bottom coil support in the coil end turn connection area, as well as additional circumferential consolidation of the end turn winding structure.

Following installation of the stator windings with the "Winding Improvement Modules" noted above, the end turn winding assembly was impact tested by the same method described earlier. The results of impact testing revealed that the natural frequency of the modified exciter end windings was 178 Hz, and the natural frequency of the modified turbine end windings was 170 Hz.

The electrical reassembly and winding modification work on the Unit 1 generator was completed on March 01, 1991. Mechanical reassembly of the generator followed, and the turbine-generator was returned to turning gear operation on March 18, 1991.

CAUSE OF EVENT:

The ground fault relay actuation was due to electrical arcing from the failed stator coil end turn to the stator cooling water system manifold. The stator coil end turn failure was due to vibration-induced fatigue cracking of the coil end turn series connection. The excessive end turn vibration which initiated the fatigue failure mechanism resulted from structural degradation of the end turn blocking and bracing. The specific cause of the blocking and bracing structural degradation cannot be determined with certainty. The generator internals are not accessible for frequent inspections, and the degraded condition of the turbine end stator windings following the failure was too widespread to isolate a single root cause. However, the most probable cause of the failure was latent damage resulting from the January 20, 1989 generator hydrogen cooling transient (refer to LER 89-005). This conclusion was reached independently by Westinghouse and a consultant employed by HL&P. It is important to note that the end turn structural damage occurred almost exclusively on the turbine end of the generator and not the exciter end, as this fact is significant with regard to root cause determination. The following is justification for this conclusion:

a) The subject hydrogen cooling transient was the most severe transient in the operating life of the generator.



CAUSE OF EVENT (Continued)

b) The latent structural damage to the end turn blocking and bracing would require several months of operation to develop, and would not be detected by nondestructive inspections

immediately following the January 20, 1989 hydrogen cooling transient.

c) The turbine end of the generator is the cold end with regard to stator water cooling flow. The highest end turn thermal stresses during the hydrogen cooling transient would develop in the region of highest temperature gradient, which is the turbine end. This explains the concentration of end turn structural damage on the turbine end of the generator.

d) A significant volume of water entered the generator during the January 20, 1989 hydrogen cooling transient due to a hydrogen cooler diaphragm rupture during the event. Analyses performed for HL&P by an independent consultant have indicated that in a steam/water environment, at the elevated temperatures (approximately 300 Deg F) seen during the hydrogen cooling transient, the end turn structural blocking and bracing materials would lose most of their mechanical strength in a few hours. Most of this water collected at the turbine end of the generator, thus also explaining the concentration of end turn structural damage on the turbine end.

A probable contributing factor was the presence of organic acid deposits on the end winding bracing, resulting from lead carbonate contamination and/or high moisture content in the hydrogen cooling gas. The following is justification for this conclusion:

a) The lead carbonate contamination was present only on the turbine end windings and not the exciter end. Formation of lead carbonate progresses through several intermediate phases which results in carbonic acid formation.

b) Analyses performed for HL&P by an independent consultant have indicated that organic acids can be produced by the reaction of pure water with some of the fabric and epoxy end turn structural blocking and bracing materials. These organic acids could then attack the structural bracing bonds.



CAUSE OF EVENT (Continued)

Operating experience on large Westinghouse generators has shown that following the initiation of some looseness in the end turn windings, end

turn vibration levels trend upward over a period of several months. Installation of an End Turn Vibration Monitoring System following the hydrogen cooling transient, might have detected increasing vibration levels and resulted in avoidance of the in-service failure.

ANALYSIS OF EVENT:

Unplanned reactor protection system actuation is reportable pursuant to 10CFR50.73(a)(2)(iv). The reactor tripped as required and plant equipment operated as expected. There was no safety injection actuation. There were no adverse radiological or safety consequences as a result of this event.

CORRECTIVE ACTION:

The following corrective actions have been implemented on the Unit 1 generator:

1) The structural integrity of the end turn windings, on both ends of the generator, has been restored by replacement of all existing end turn structural supports, and upgraded by installation of "Winding Improvement Modules." This action was completed prior to the end of the 1RE03 refueling outage.

2) An End Turn Vibration Monitoring System has been installed to provide continuous on-line monitoring capability of end turn vibration levels on both the exciter end and turbine end of the generator. This action was completed prior to the end of the 1RE03 refueling outage.

3) A dual tower hydrogen gas dryer has been installed to provide continuous hydrogen dehydration capability during both on-line and off-line conditions. This dryer supplements the existing single tower dryer, which provides dehydration only when the generator is on-line. This action was completed prior to the end of the 1RE03 refueling outage.

The following corrective actions will be implemented on the Unit 2 generator:

4) The End Turn Vibration Monitor, identical to the Unit 1 installation, will be installed on Unit 2 by the end of the 2RE02 refueling outage.

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CORRECTIVE ACTION (Continued):

5) The dual tower hydrogen gas dryer, identical to the Unit 1 installation, will be installed on Unit 2 by the end of the 2RE02 refueling outage.

6) The following inspections and activities will be performed during the 2RE02 refueling outage:

a) Impact testing of the end turn windings.
b) Nondestructive testing of all stator coil header caps for fatigue crack detection.
c) Machining of high mechanical stress concentration areas on the stator coil header caps to reduce those stresses.

The following general corrective action has also been implemented:

7) A Turbine-Generator Task Force, consisting of HL&P and Westinghouse engineering personnel, was initiated in February, 1991. This task force will meet periodically to address issues of concern regarding the Westinghouse turbine-generator, and will also serve as a forum to improve communications and exchange of relevant operational information between HL&P and Westinghouse.

ADDITIONAL INFORMATION:

There have been no previous events at STPEGS regarding a stator coil end turn failure which resulted in a generator ground fault and subsequent reactor trip.

There have been two previous events of stator coil end turn failures, very similar to the STPEGS failure, on large domestic Westinghouse four-pole generators. These events occurred at Public Service Electric & Gas Salem Unit 1 in February, 1984, and Salem Unit 2 in October, 1984.

The information regarding the STPEGS Unit 1 generator hydrogen cooling transient was described in LER 89-005, transmitted to the NRC by letter ST-HL-AE-2993 dated February 20, 1989.

The STPEGS Unit 1 generator is a 1504.8 MVA, four-pole, 1800 rpm machine with water cooled stator coils and hydrogen cooled rotor, manufactured by Westinghouse.

HL&P is presently considering installation of the "Winding Improvement Modules" in the Unit 2 generator.

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Figure 1 "Stator Coil Cross Sections" omitted.



Figure 2 "End Turn Windings and Cooling Water Manifold" omitted.



The Light
company
South Texas Project Electric Generating Station
P.O. Box 289 Wadsworth, Texas 77483

Houston Lighting & Power

May 01, 1991
ST-HL-AE-3758
File No.: G26
10CFR50.73

U. S. Nuclear Regulatory Commission
Attention: Document Control Desk
Washington, DC 20555

South Texas Project Electric Generating Station
Unit 1
Docket No. STN 50-498
Revision 1 to Licensee Event Report 90-025
Regarding Reactor Trip Due to a
Generator Ground Fault Relay
Actuation Caused by a Stator Coil End Turn Failure

Pursuant to 10CFR50.73, Houston Lighting & Power Company (HL&P) submits the attached Revision 1 to Licensee Event Report 90-025 regarding a reactor trip due to a generator ground fault relay actuation caused by a stator coil end turn failure. This event did not have any adverse impact on the health and safety of the public.

If you should have any questions on this matter, please contact Mr.

C. A. Ayala at (512) 972-8628 or myself at (512) 972-7205.

William J. Jump
Manager
Nuclear Licensing
CMH/kmd

Attachment: South Texas, Unit 2
LER 90-025 Revision 1

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A Subsidiary of Houston Industries Incorporated



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Revised 01/29/91
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